7.0 Acoustic Surveys and Results

This section describes various acoustics surveys, their design, and results.

7.1. Survey design and Cruise Tracks

7.1.1. 1998 Surveys

Acoustic survey objectives during September-October 1998 were focused on locating spawning and pre-spawning concentrations of Atlantic herring in the Gulf of Maine and on Georges Bank. A series of fine scale and broad scale systematic parallel transect surveys were completed during the 1998 Atlantic Herring Hydroacoustic Survey in the Gulf of Maine. Fine-scale systematic grids of transects spaced 2 nmi were surveyed to cover important historic spawning areas and sites of recent commercial activity (Figure 7.1). The broader scale survey (with 20 nmi spacing) was designed to encounter herring over the entirety of the Gulf of Maine region (Figure 7.2).

On Georges Bank, two surveys were conducted to sample herring in the large historic spawning site that runs from Nantucket Shoals to eastern Georges Bank. A systematic zigzag survey design was employed (Figure 7.3). Time constraints allowed for only a small portion of the Georges Bank site to be covered.

7.1.2. 1999 Surveys

In September-October 1999, important herring spawning areas in the Gulf of Maine and on Georges Bank were surveyed to acquire information on spatial and temporal distribution patterns and abundance. As in 1998, sites were covered with systematic parallel designs in 1999 in the Gulf of Maine (Figure 7.4). The extent of spatial coverage was broadened and two zigzag surveys with 10 nmi spacing at the nodes were completed. In addition, a systematic parallel survey was conducted over the entire Georges Bank region (Figure 7.5). During this survey, no herring were found on the southern side of Bank.

7.1.3. 2000 Surveys

During September-October 2000 survey sites in the Gulf of Maine received the same level of coverage as in the previous two years (Figure 7.6). On Georges Bank, a more extensive coverage of the historic spawning sites was completed. Three survey designs (parallel, zigzag, and stratified random) were employed to sample herring distribution and abundance (Figures 7.6-7.8). These surveys were designed to cover the entire extent of the spawning aggregations and to provide valuable additional spatial, temporal, and quantitative information for conducting future surveys. The zigzag and parallel surveys used 10 nmi spacing between transects.

Three survey strata were chosen for the stratified random survey, corresponding to western (Strata 1), central (Strata 2), and eastern (Strata 3) strata areas (Figure 7.9). The strata were chosen on the basis of bathymetry, geographic features (*i.e.*, the Great South Channel, Cultivator Shoals, and the Northern Edge of Georges Bank), and previous knowledge of the spatial distribution of herring in these areas. Transects were allocated to strata based on the total length of transects and the strata area. There were 13 transects available in stratum 1 and 2 and 12 in strata 3. The set of potential transects for the stratified random survey were spaced at 5 nmi intervals. Five randomly selected transects were surveyed in strata 1 and 2 and four in stratum 3 (Figure 7.9).

7.1.4. 2001 Surveys

In September-October 2001, specific sites in the Gulf of Maine again received the same level of coverage as in the previous years (Figure 7.10). Coverage of the Georges Bank region was similar to the 2000 Atlantic Herring Hydroacoustic Survey, but some transects were extended to provide more complete coverage of the spawning concentrations (Figure 7.11-7.13).

Several additional transects were added to the stratified random survey in 2001 to increase the sample size in each strata. The spacing of the possible transects for the stratified random survey were changed from 5 nmi to 3 nmi and the number of possible transects in both stratum 1 and 2 were changed to 21, and to 19 in stratum 3 (Figure 7.14). Of these, seven transects were sampled in strata 1 and 2, and six in stratum 3.

7.1.5. 2002 Surveys

In 2002, the first leg of surveying operations was devoted to a systematic parallel design that covered the Jeffreys Ledge area much more extensively than in previous years. This survey extended over depths up to 200 m and covered the Jeffreys Basin area to the west of Jeffreys Ledge and areas to the east (Figure 7.15).

An enhanced version of the systematic parallel survey designs used in the the 2000 and 2001 surveys on Georges Bank was deployed during 2002. More transects were added and additional mid-water trawl stations were completed (Figure 7.16). The area of coverage was somewhat larger than in the two previous years and the transect spacing was decreased to 8 nmi.

7.2. Atlantic Herring Acoustic Survey Results

All of the Gulf of Maine acoustic surveys used a downward looking EK500 SIMRAD echosounder operating at 12, 38, and 120 kHz. In this report, analyses are presented using only the 38 kHz data from Georges Bank.

7.2.1. 1998

The 1998 survey operations only covered a portion of the herring spawning grounds on Georges Bank and transects were not sufficiently long to fully sample the extent of the distribution in the north-south direction (Figure 7.17). Herring backscatter (Sa) was confined to a narrow band along the 100 m contour (Figure 7.17). Herring appeared to be present at the northern end of most transects and in shallower depths along the 100 m contour (Figure 7.17). Transects that extended further on the Bank (< 50 m depth) contained few if any herring.

7.2.2. 1999

In 1999, a much larger area was surveyed on Georges Bank. Herring were present along the 100 m contour and further to the north in deeper water (>200 m) (Figures 7.18, 7.19). Herring were again present at the northern end of the survey transects, indicating that some fish were being missed by the survey beyond the northern limit of the transects. Portions of transects that extended into shallow water (< 50 m depth) contained few herring (Figures 7.18, 7.19).

On the parallel survey in 1999, herring were found only along the Great South Channel, West of Cultivator Shoals, and on the Northern Edge. Herring were present along the 100 m contour and further to the north in deeper water (>200 m) (Figure 7.20). Herring were again present at the northern limit of some of the survey transects. Portions of transects that extended into shallow water (< 50 m depth) on Georges Bank contained few herring (Figures 7.20).

7.2.3. 2000

In 2000, three different survey designs were used to sample herring on Georges Bank. In the systematic zigzag survey, herring were distributed in a broad band from west to east over the whole survey area (Figure 7.21). Fish were abundant between the 100 and 200 m contours, with fish particularly abundant in the middle section of the survey area, adjacent to the Cultivator Shoals region. Fewer herring occurred at the western and eastern most locations in the survey, and most transects began and ended little or no herring.

In the systematic parallel survey, herring occurred from Nantucket Shoals to the northern edge of Georges Bank (Figure 7.22). Herring were abundant between the 100 and 200 m isobaths and broadly distributed in the western and central parts of the survey area. Herring were most abundant in the central part of the area, with few fish found at the western and eastern extremes of the area. Most transects began and ended in areas with little or no herring.

The stratified random survey confirmed the broad east-west distribution of herring. Herring were very abundant between the 100 and 200+ contours and were widely distributed in the western and central areas (Figure 7.23). Abundance was greatest in the central area with few herring observed at western and eastern transects.

7.2.4. 2001

In 2001, herring were very abundant between 50 and 200 meters and were concentrated in the central and western areas adjacent to Georges Bank in the parallel survey (Figure 7.24). Most of the transects began and ended with few or no herring.

Herring were very abundant along the 50-100+ m contours from the Great South Channel to the Northern Edge of Georges Bank in both the zigzag and stratified random surveys. The highest Sa values were obtained in the central region of the distribution, in deeper water to the west, and along the 100 m contour to the east. (Figure 7.25).

7.2.5. 2002

In the 2002 survey, herring were abundant along the 100 m contour and in deeper water as in previous years, and the highest backscatter values were observed in the central and eastern parts of the pre-spawning aggregation (Figure 7.27).

7.3. Length-Weight and Total Length Relationships

Mid-water trawl hauls were conducted during all surveys to confirm the species composition of the acoustic backscatter. Mid-water trawl samples were separated by species, weighed (g), measured (FL, cm), and all information recorded on trawl logs or in the FSCS electronic database management system.

Length-weight equations for Atlantic herring were estimated from herring sampled during autumn bottom trawl surveys. Length-weight results from the autumn bottom trawl surveys were used because fish collected during the acoustic surveys were experiencing rapid changes in weight due to spawning, and were not be useful for estimating a general equation. Non-linear regression was used to estimate the parameters of the length weight equation as

$$W_t = aL^b$$

where W_t is the weight in kg, L is fork length in cm and a and b are parameters. Parameters for 1999-2002 are shown in Table 7.1.

Data collected in 1999, were used in developing a fork length-total length conversion equation. Fork length measurements were converted to total length using:

$$L_{TL} = 0.01 + 1.102972 L_{FL}$$

Length compositions from each survey during 1999-2002 were converted to total length and then used in the target strength analyses.

7.4. Herring Backscatter (Sa)

Species compositions from mid-water trawling operations were used to partition the total backscatter into components. Atlantic herring Sa values for all surveys were plotted in ArcView and polygons drawn to encompass the herring distribution. Areas of each survey region were estimated using the polygon area feature in ArcView. Data from 1999-2002 were then analyzed with the geostatistical methods package available in SPLUS. Herring Sa data were converted from longitude and latitude (in decimal degrees) to a grid of observations in nautical mile format. After correction for geometric anisotrophy in most cases, and setting the maximum distance at 50 n.mi., robust variograms were fit for all the surveys. Parameters from variogram fits were roughly similar among the designs and years, and spherical variograms were used to describe the spatial structure in the herring Sa (Figure 7.28).

A consistent spatial autocorrelation pattern existed in the data used to model herring abundance. Kriging was used to estimate the mean and standard deviation of the herring backscatter from surveys conducted during 1999-2002. These analyses produced mean herring backscatter values that ranged between 1036-3385 during 1999, 1065-1824 in 2000, 1256-1823 in 2002, and 567 in 2002 (Table 7.2). The standard deviation of the herring backscatter is also listed in Table 7.2. The CV of these estimates was much smaller using the model based approach than with the design approach with ranges between 9.8% and 20.9% in 1999, 10%-16.9% in 2000 and 9.9%-15.3% in 2001, and 13.6% in 2002 (Table 7.2).

7.5. Herring Acoustic Target Strength

As no local target strength (TS) equation is currently available for converting echo intensity to herring biomass, the intercepts from eleven target strength equations for other herring stocks in the North Atlantic were used (ICES 2001) (Table 7.3).

These studies were all conducted at similar frequencies (~38kh). The intercepts were used in the standard TS equation (Foote 1991) as:

$$TS = 20\log_{10} TL - I$$

where TS is the target strength, TL is the average total length of the entire length composition surveyed, and I is the intercept. The TS equation with each intercept was used to calculate an acoustic back scattering cross sectional area as:

$$\sigma = 4\pi 10^{TS/10}$$

where σ is the acoustic backscattering cross sectional area. For each intercept, TS was calculated for each length in the survey length composition and then weighted by the numbers at length. A weighted mean σ was produced for each intercept and used to calculate total abundance as:

$$N = {SA}/{\sigma} * A$$

where N is the total number of herring in the survey, SA is the mean backscatter for the survey, and A is the total surveyed area(in square nautical miles) of the survey area. Biomass for each intercept was calculated as:

$$B = N * wt$$

where B is the total biomass and wt is the mean weight, weighted by the length composition. This process was repeated for all eleven TS intercepts and an average biomass for the each survey was then calculated (Table 7.4).

During 1999-2001, three surveys were completed in each year on Georges Bank. Biomass estimates from these surveys were weighted by the inverse of the geostatistical CV for each survey, and a weighted mean biomass calculated for each survey year (Table 7.4).

7.6. Bootstrap Analysis

A bootstrap analysis was used to evaluate the precision of the survey biomass estimates. The mean areal herring backscatter for each systematic parallel or zigzag survey was calculated using the methods described by Jolly and Hampton (1990).

$$\overline{SA} = \frac{1}{n}\sum_{i=1}^{n} W_i Sa_i$$

where $\overline{SA}$ is the mean herring backscatter, W_i is the weighting coefficient for transect length, Sa_i is the mean herring backscatter for each transect, and n is the number of transects, with

$$W_i = \frac{L_i}{\overline{L}},\ \overline{Sa}_i = \frac{\sum Sa_k}{n(esdu)_k}$$

where L_i is the individual transect length, the mean $\overline{L}$ is the mean transect length, $\overline{Sa}_i$ is the mean herring backscatter for each transect, Sa_k is the herring backscatter for each elementary sampling distance unit (ESDU = 0.5 nmi) and $n(esdu)_k$ is the number of segments in each transect, with

$$\overline{L}_i = \frac{1}{n}\sum L_i$$

The mean herring backscatter for a stratified random survey was calculated as:

$$\overline{Sa}_i = \frac{1}{n}\sum_{j=1}^{n_i} W_{ij}\overline{Sa}_{ij}$$

where mean $\overline{Sa}_i$ is the mean herring backscatter for the ith stratum, W_{ij} and $\overline{Sa}_{ij}$ are the weighting coefficients and mean herring backscatter for the ith stratum and jth transect. The stratified mean herring backscatter was also weighted by the area of each stratum as:

$$\overline{SA} = \frac{\sum A_i \overline{Sa}_i}{\sum A_i}$$

where mean $\overline{SA}$ is the stratified mean herring backscatter and A_i are the area for each stratum. Point estimates from the surveys are given in Table 7.5.

Some of the survey data were produced from systematic designs, which according to classical statistical approaches cannot be used to produce an estimate of variance. Therefore, bootstrap results from all the surveys were scaled by the geostatistical variance as;

$$\bar{S}a = u_{boot} - (u_{geo} - u_{boot}) * sqrt(\sigma^2{}_{geo} / \sigma^2{}_{boot})$$

This approach is outlined in Simmonds (2002). The transect mean Sa's from each survey were bootstrapped 2500 times and scaled with the geostatistical variance using the above equation.

The median biomass from bootstrap replicates ranged from 1.14-1.40 million mt during 1999, 1.26-1.76 million mt in 2000, 1.47-2.34 million mt in 2001, and was 0.838 million mt in 2002 (Figures 7.29-7.32).

Table 7.1. Parameters for length weight equations for Atlantic herring from NMFS autumn research vessel bottom trawl surveys in the Gulf of Maine-Georges Bank Region.

Year	a	b
1999	0.0000115	2.924232
2000	0.0000459	2.502584
2002	0.0000160	2.810323
2002	0.0000160	2.810323

Table 7.2. Mean herring backscatter (Sa) and SD of backscatter from acoustic surveys on Georges Bank during 1999-2002.

Survey	Mean Sa	SD	Survey Area nmi^2
1999			
Zigzag 1	3385.122	634.372	2322.13
Zigzag 2	2731.073	569.702	2116.66
Parallel	1036.231	101.447	6108.88
2000			
Zigzag	1064.997	106.499	6297.86
Parallel	1824.410	209.625	4376.42
Stratified random	1191.143	201.184	7085.98
2001			
Zigzag	1453.494	156.977	6539.68
Parallel	1822.759	180.271	6405.58
Stratified random	1256.025	192.172	7284.11
2002			
Parallel	566.997	76.885	7658.70

Table 7.3. Intercepts from target strength equations from studies on herring stocks in the North Atlantic.

	Study	Intercept
1	Hagstrom&Rottigen 1982	-73.5
2	Halldorsson & Reynesson 1983	-69.4
3	Degnbol et al 1985	-72.6
4	Lasson and Staehr 1985	-70.8
5	Foote et al. 1986	-72.1
6	Foote et al. 1987	-71.9
7	Rudstam et al. 1988	-69.9
8	Bailey and Simmonds 1990	-71.2
9	Reynisson 1993	-67.1
10	Misund and Beltstad 1995	-69.8
11	Vabo et al. 1999	-67.6

Table 7.4. Geostatistical estimates of biomass, CV, CV inverse, weighted biomass (W) and weighted CV (W) for Acoustic surveys on Georges Bank during 1999-2002.

	Biomass	CV	1/CV	W Biomass	W CV
1999					
Zigzag1	1.4173	18.74	0.0534		
Zigzag2	1.0409	20.86	0.0479	1.19276E6	10.712
Parallel	1.1467	9.79	0.1021		
2000					
Parallel	1.5025	11.49	0.0870		
Zigzag	1.2680	10.00	0.1000	1.426880E6	7.222
S random	1.5838	16.89	0.0592		
2001					
Parallel	2.1484	9.89	0.1011		
Zigzag	1.6172	10.80	0.0926	1.819177E6	6.604
S random	1.5960	15.30	0.0654		
2002					
Parallel	0.7628	13.56		0.762759E6	13.560

Table 7.5. Point estimates of mean Sa and biomass (million mt) from standard statistical analysis for surveys on Georges Bank during 1999-2002.

Year	Survey	Mean Sa	Biomass (million mt)
1999	Zigzag 1	3444.588	1.4422
	Zigzag 2	3059.560	1.1661
	Parallel	1164.686	1.2889
2000	Zigzag	1053.267	1.2540
	Parallel	2132.484	1.7562
	Stratified Random	1291.377	1.7171
2001	Zigzag	1447.870	1.6109
	Parallel	1997.915	2.3549
	Stratified Random	1168.296	1.4845
2002	Parallel	627.614	0.8443

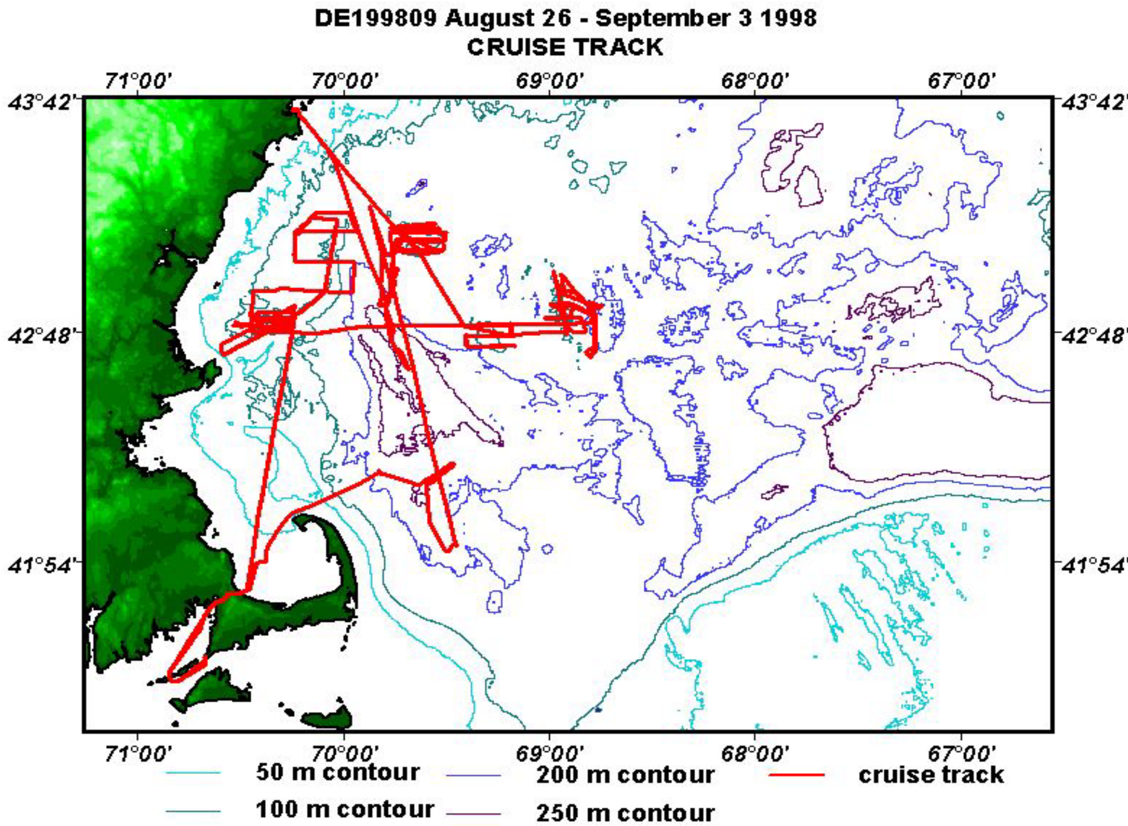

Figure 7.1. Cruise tracks for surveys on Jeffreys Ledge, Platts Bank, Cashes Ledge and Fippennies Ledge during the 1998 Atlantic Herring Hydroacoustic Survey.

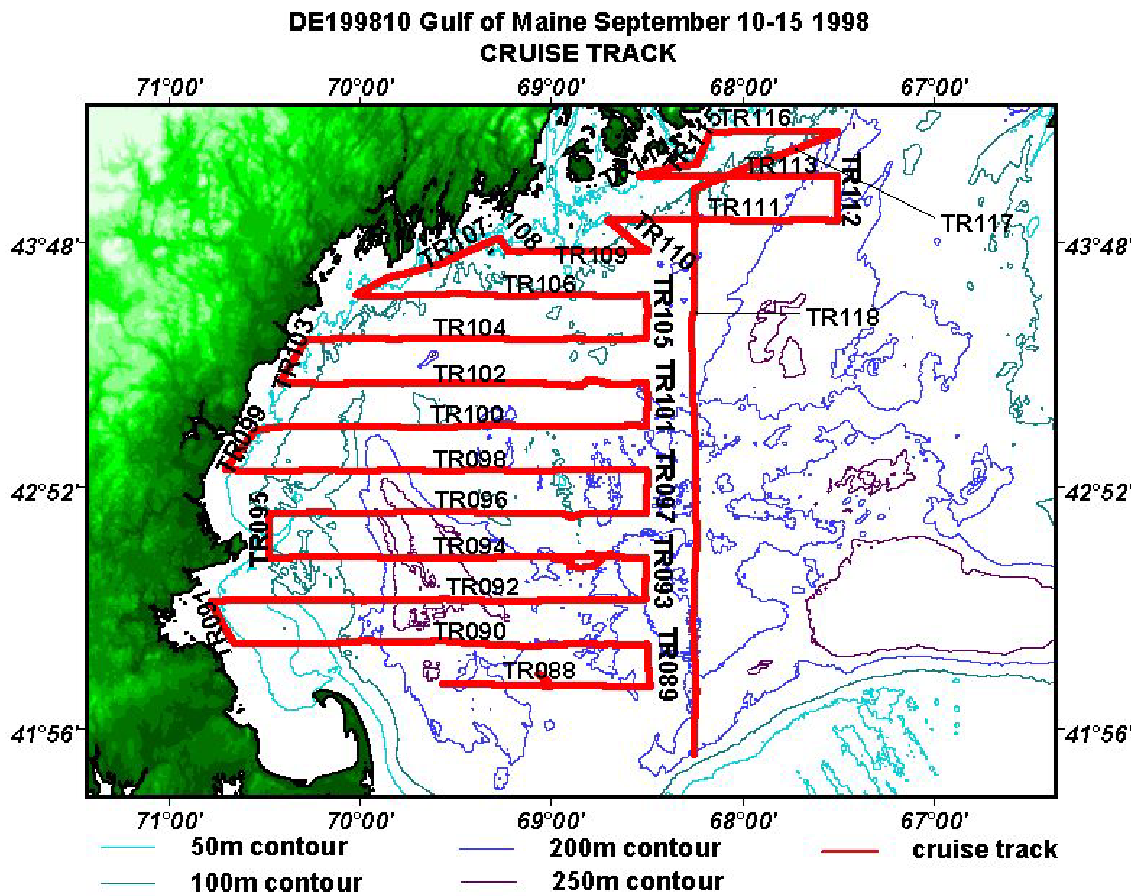

Figure 7.2. Cruise track for the systematic parallel survey (20 nautical miles spacing between transects) in the Gulf of Maine during the 1998 Atlantic Herring Hydroacoustic Survey

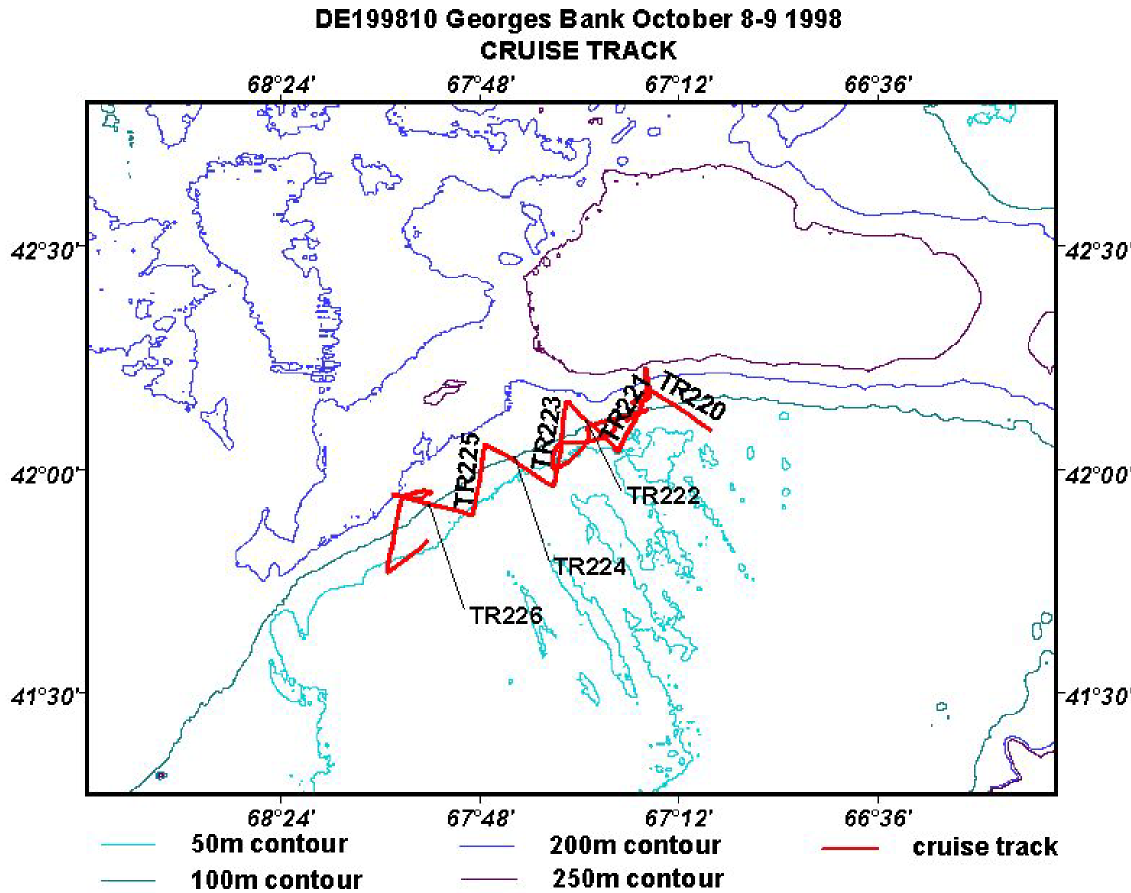

Figure 7.3. Cruise track for one zigzag survey on the northern edge of Georges Bank during the 1998 Atlantic Herring Hydroacoustic Survey.

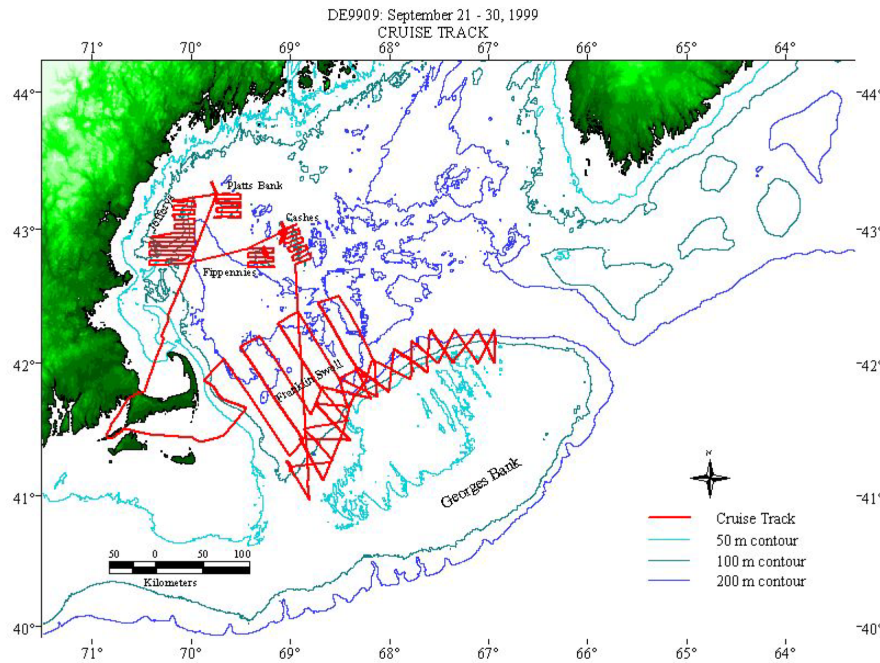

Figure 7.4. Cruise track for surveys on Jeffreys Ledge, Platts Bank, Fippennies Ledge, Cashes Ledge, Franklin Swell, and Georges Bank during the 1999 Atlantic Herring Hydroacoustic Survey. Two systematic zigzag survey designs were conducted on Georges Bank, while systematic parallel surveys were conducted in the Gulf of Maine survey areas.

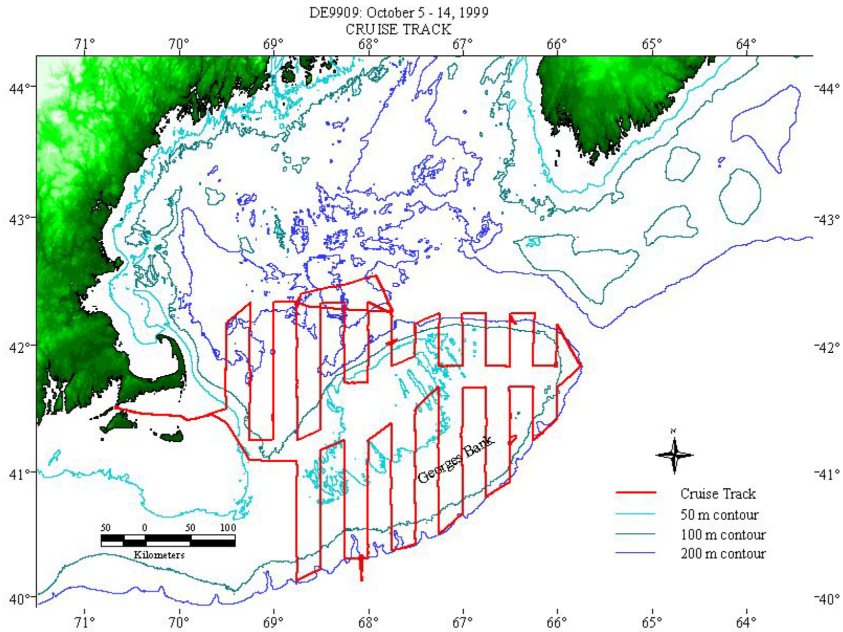

Figure 7.5. Cruise track for the systematic parallel survey circumscribing Georges Bank during the 1999 Atlantic Herring Hydroacoustic Survey

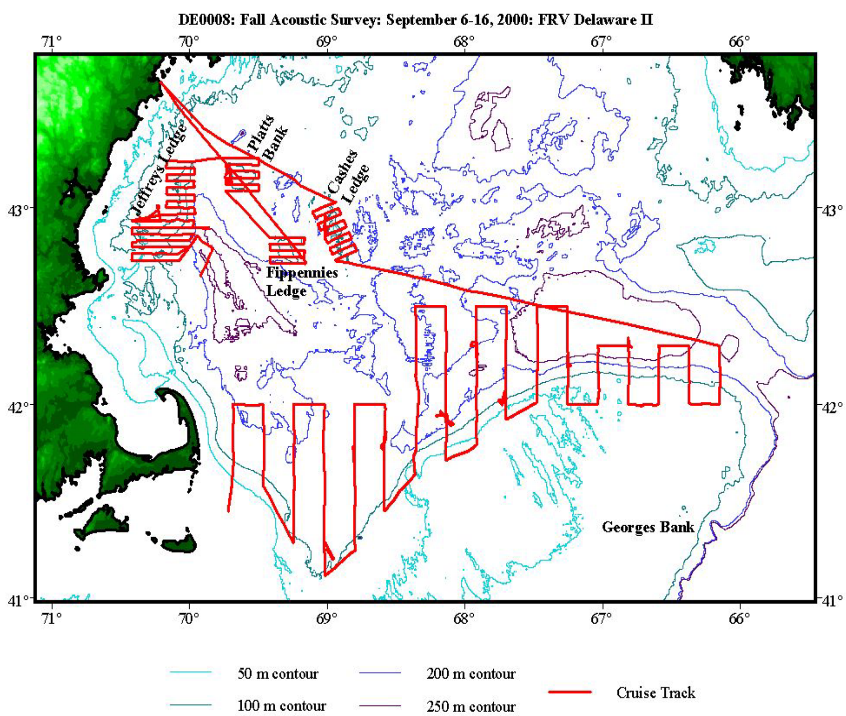

Figure 7.6. Cruise track for systematic parallel surveys conducted on Jeffreys Ledge, Platts Bank, Fippennies Ledge, Cashes Ledge, and Georges Bank during the 2000 Atlantic Herring Hydroacoustic Surveys

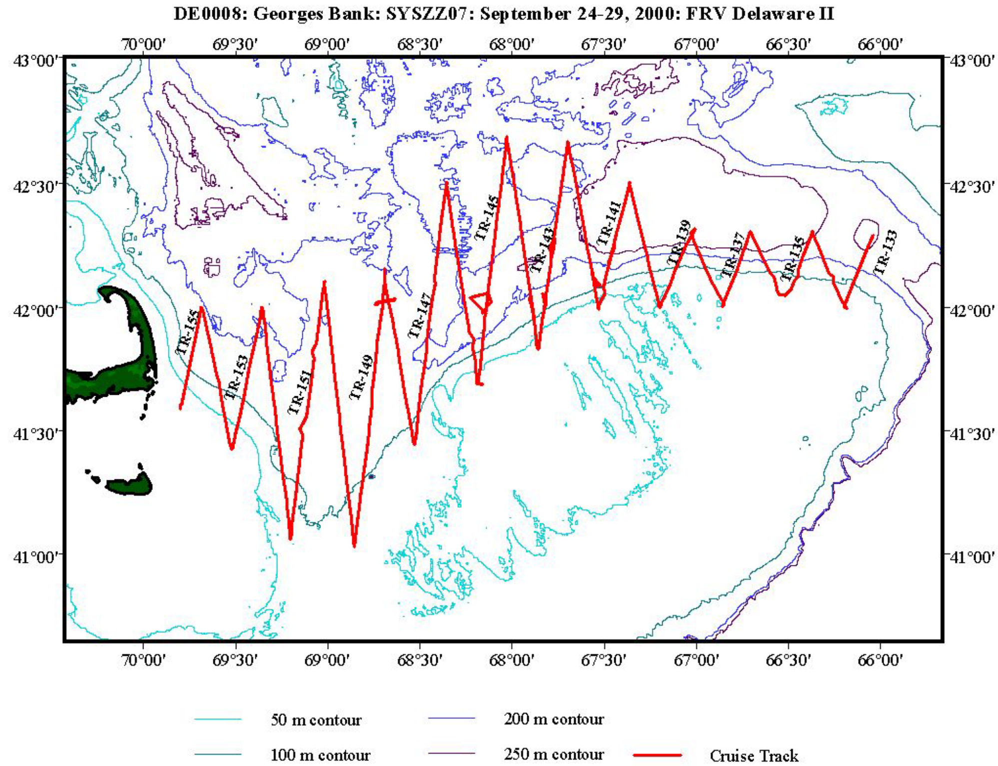

Figure 7.7. Cruise track for the systematic zigzag survey on Georges Bank during 2000.

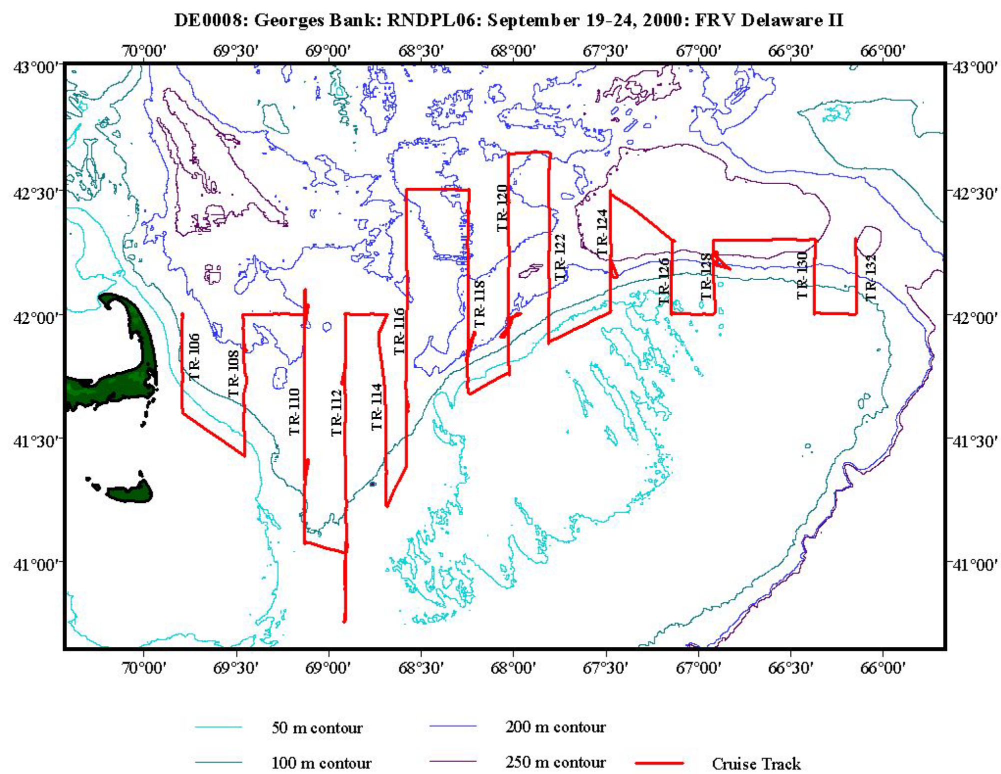

Figure 7.8. Cruise track for the stratified random survey design on Georges Bank during 2000.

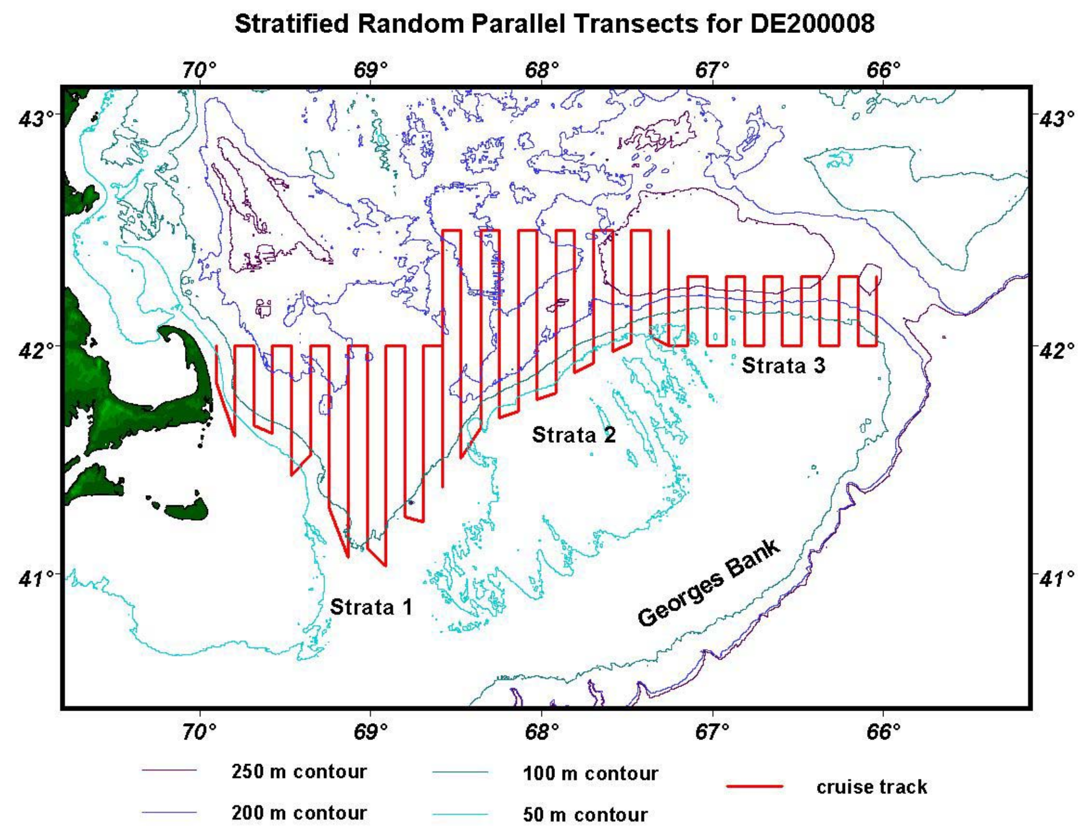

Figure 7.9. Complete set of potential stratified random parallel transects for surveyin Atlantic herring on Georges Bank during the 2000 Atlantic Herring Hydroacoustic Survey.

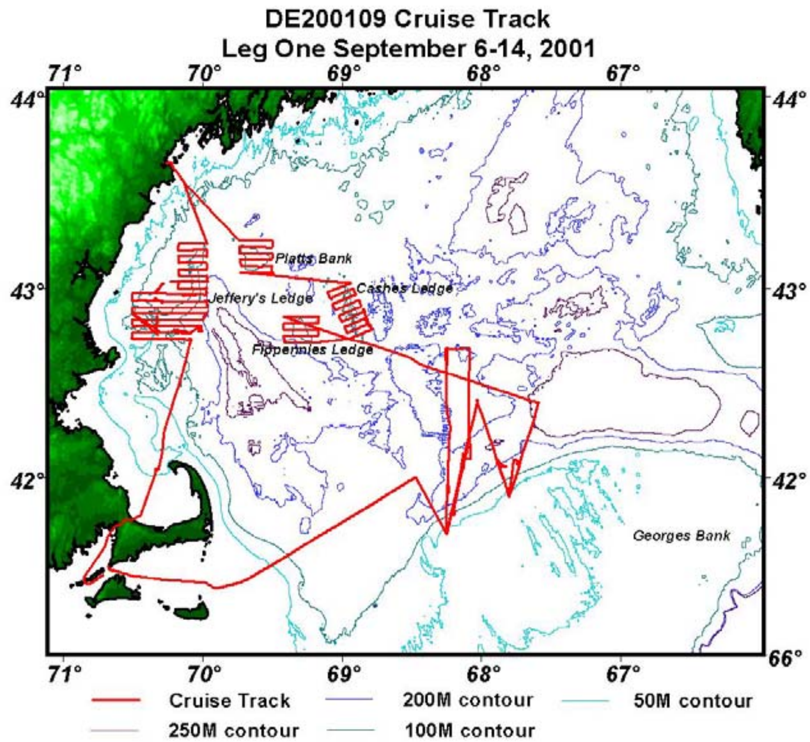

Figure 7.10. Cruise tracks for systematic parallel surveys on Jeffreys Ledge, Platts Bank, Fippennies Ledge, and Cashes Ledge during 2001. The cruise tracks on Georges Bank represent experimental work with broadband and low-frequency acoustics.

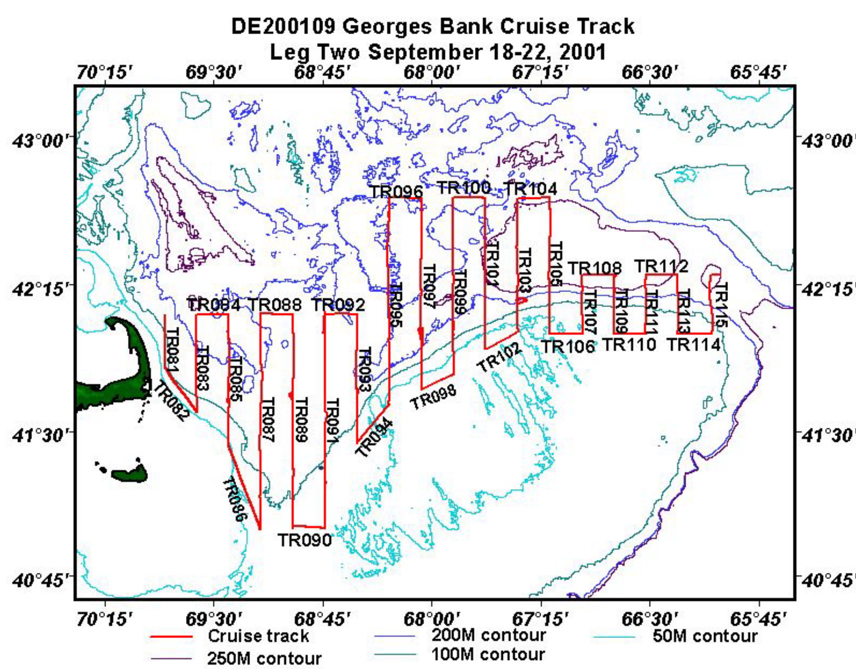

Figure 7.11. Cruise track for the systematic parallel survey on Georges Bank during the 2000 Atlantic Herring Hydroacoustic Survey.

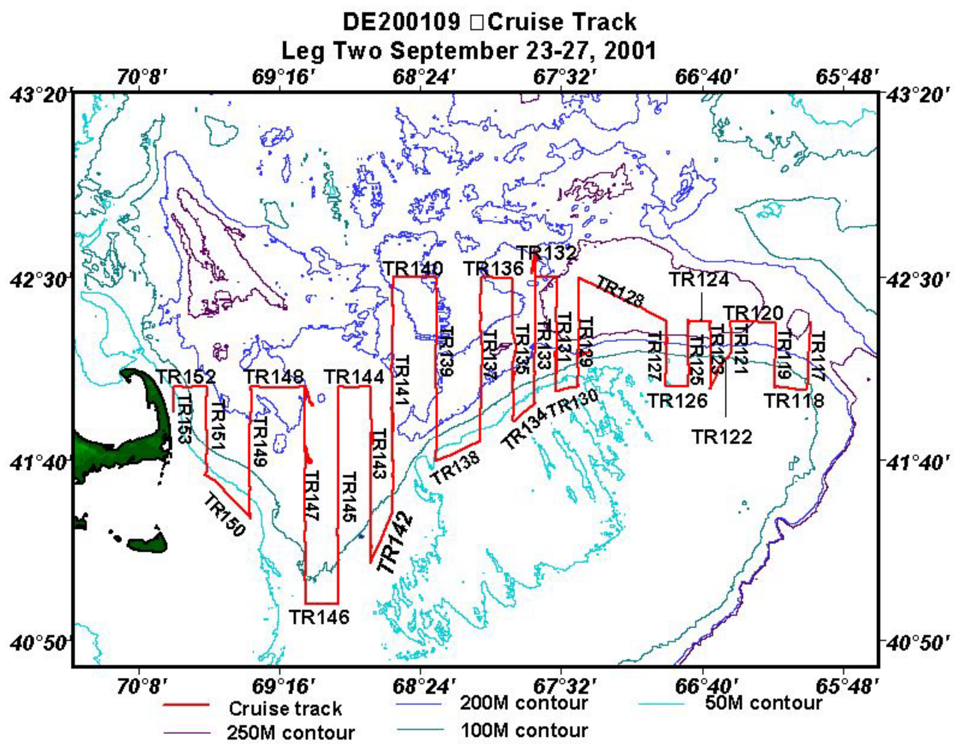

Figure 7.12. Cruise track for the random parallel survey on Georges Bank during the 2001 Atlantic Herring Hydroacoustic Survey.

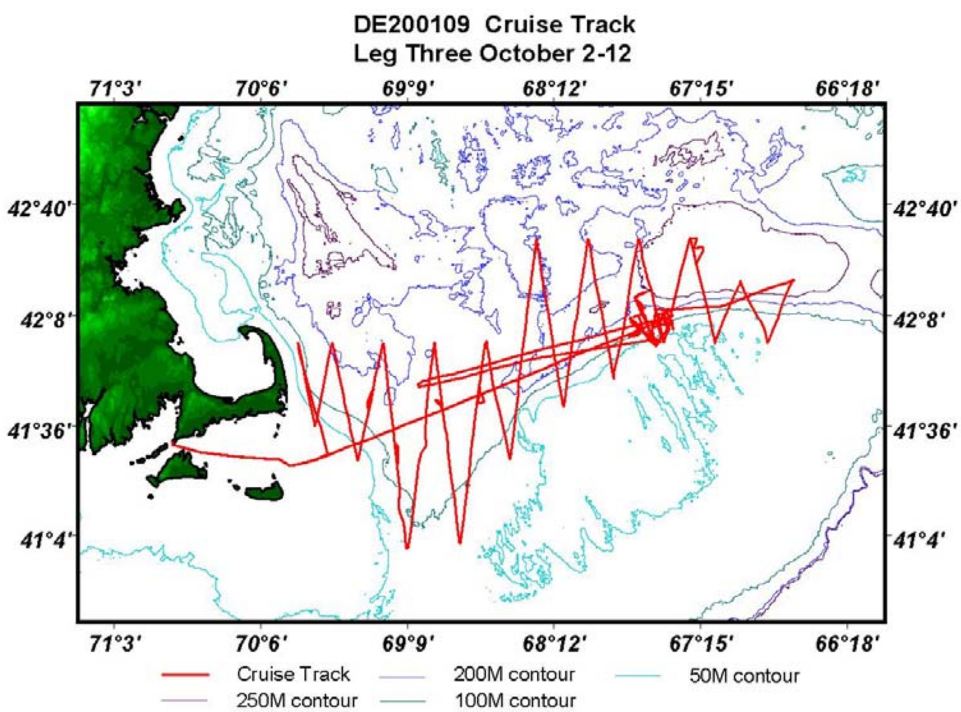

Figure 7.13. Cruise track for systematic zigzag survey and experimental work on Georges Bank during the 2001 Atlantic Herring Hydroacoustic Survey.

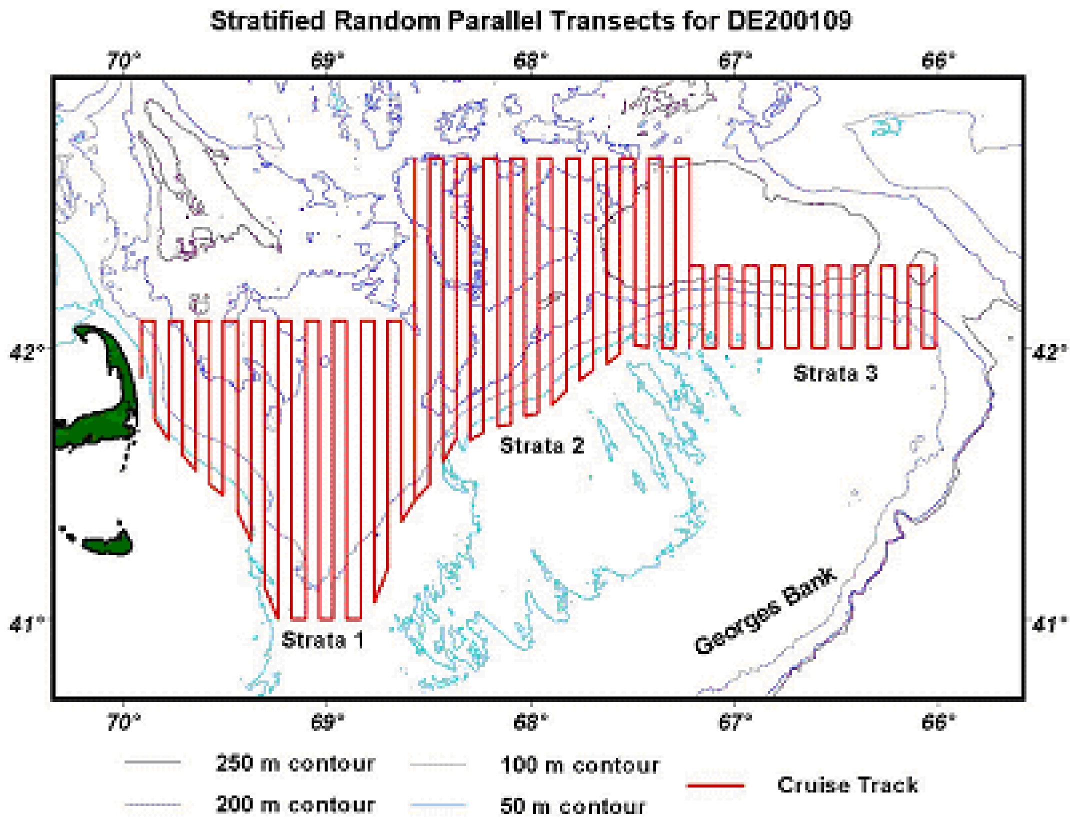

Figure 7.14. Stratified random parallel transect design for surveying Atlantic herring on Georges Bank during 2001

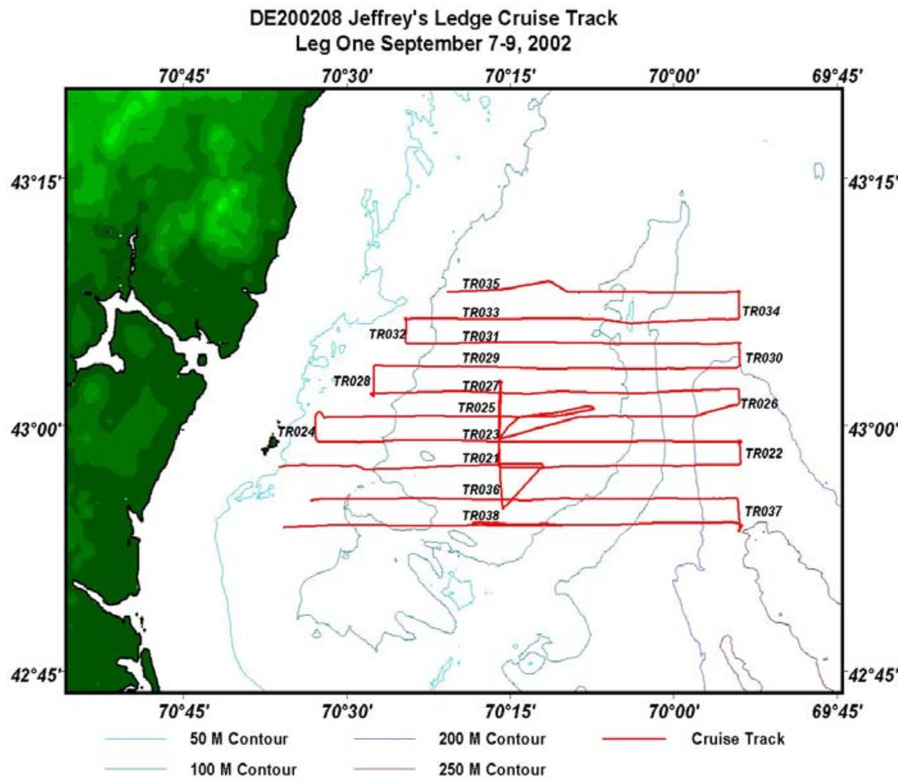

Figure 7.15. Parallel design for surveying Atlantic herring on Jefferys Ledge during 2002

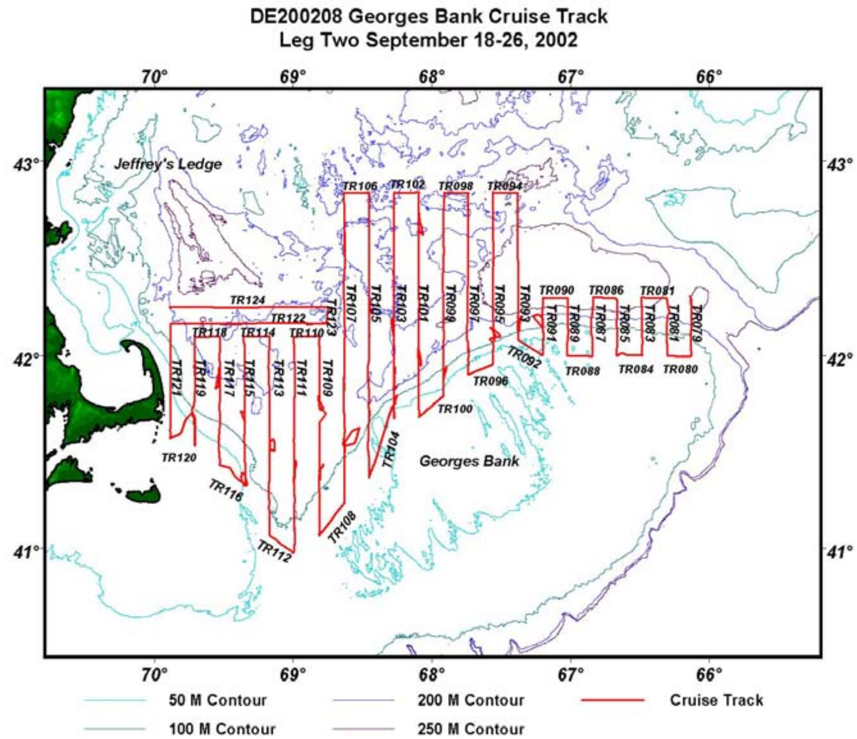

Figure 7.16. Parallel design for surveying Atlantic herring on Georges Bank during 2002.

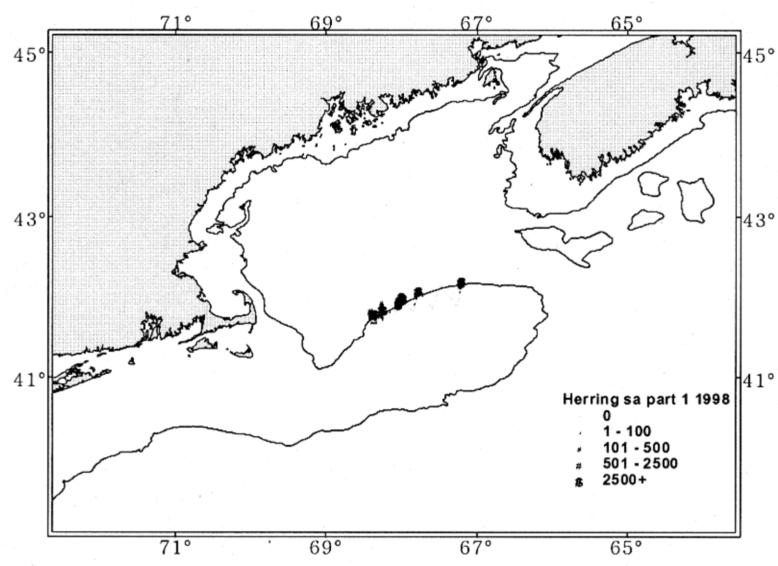

Figure 7.17. Herring backscatter (Sa) on transects from a zigzag survey design on Georges Bank during 1998.

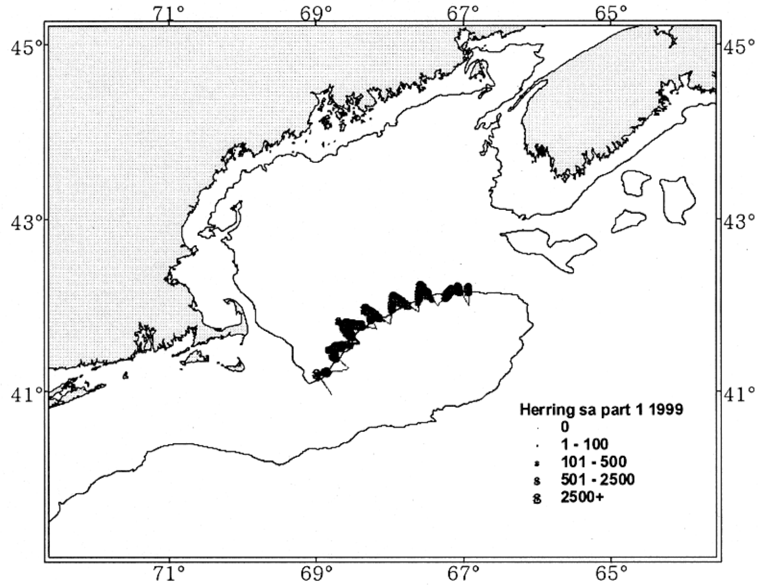

Figure 7.18. Herring backscatter on transects from a zigzag survey (part 1) design on Georges Bank during 1999.

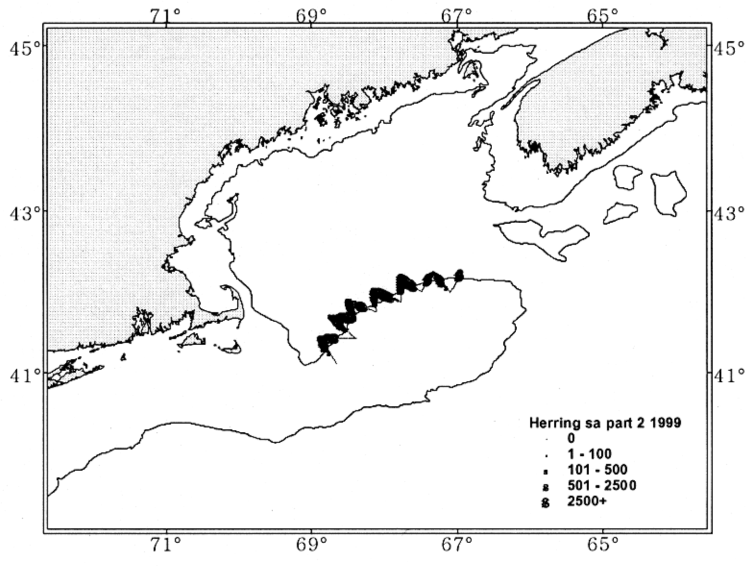

Figure 7.19. Herring backscatter on transects from a zigzag survey (Part 2) on Georges Bank during 1999.

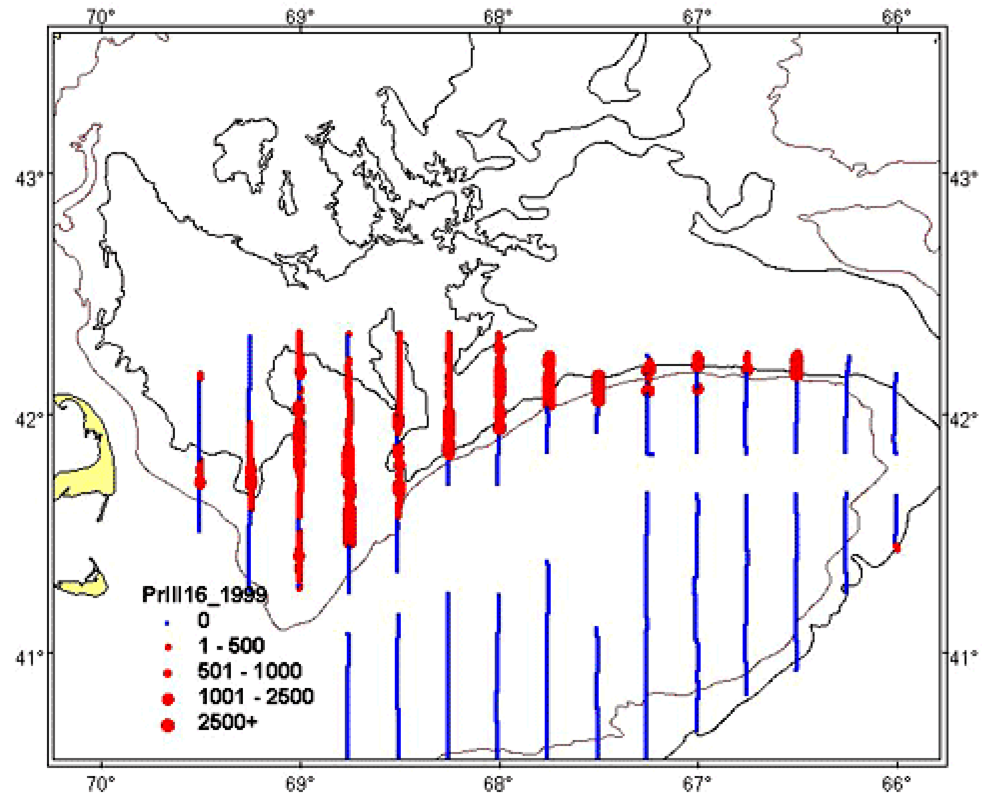

Figure 7.20. Herring backscatter (Sa) on transects from a parallel design on Georges Bank during 1999.

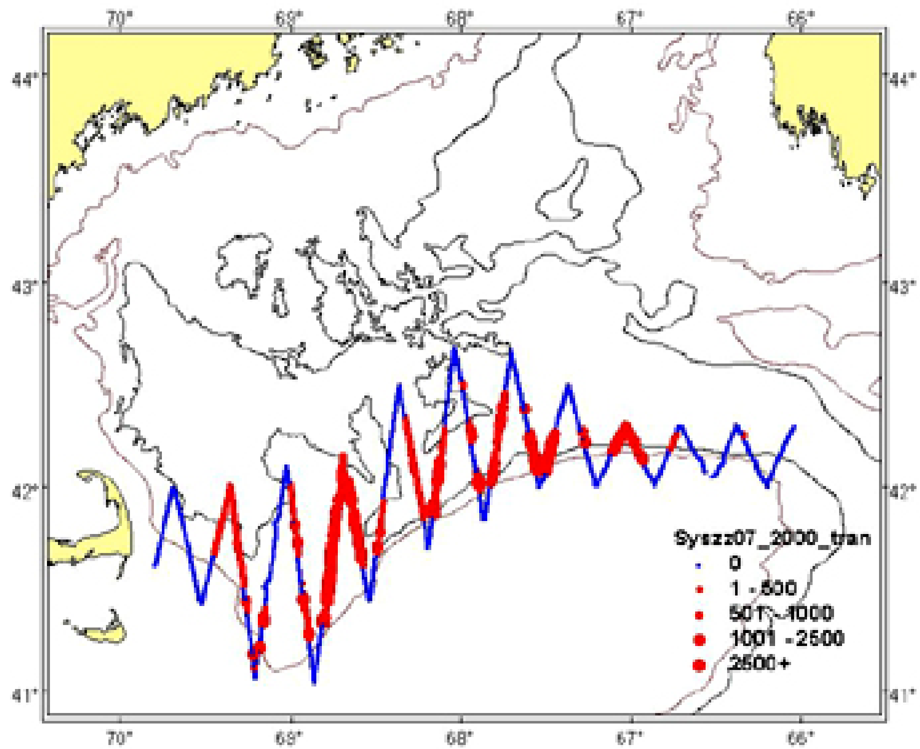

Figure 7.21. Herring backscatter (Sa) on transects from a zigzag survey design on Georges Bank during 2000.

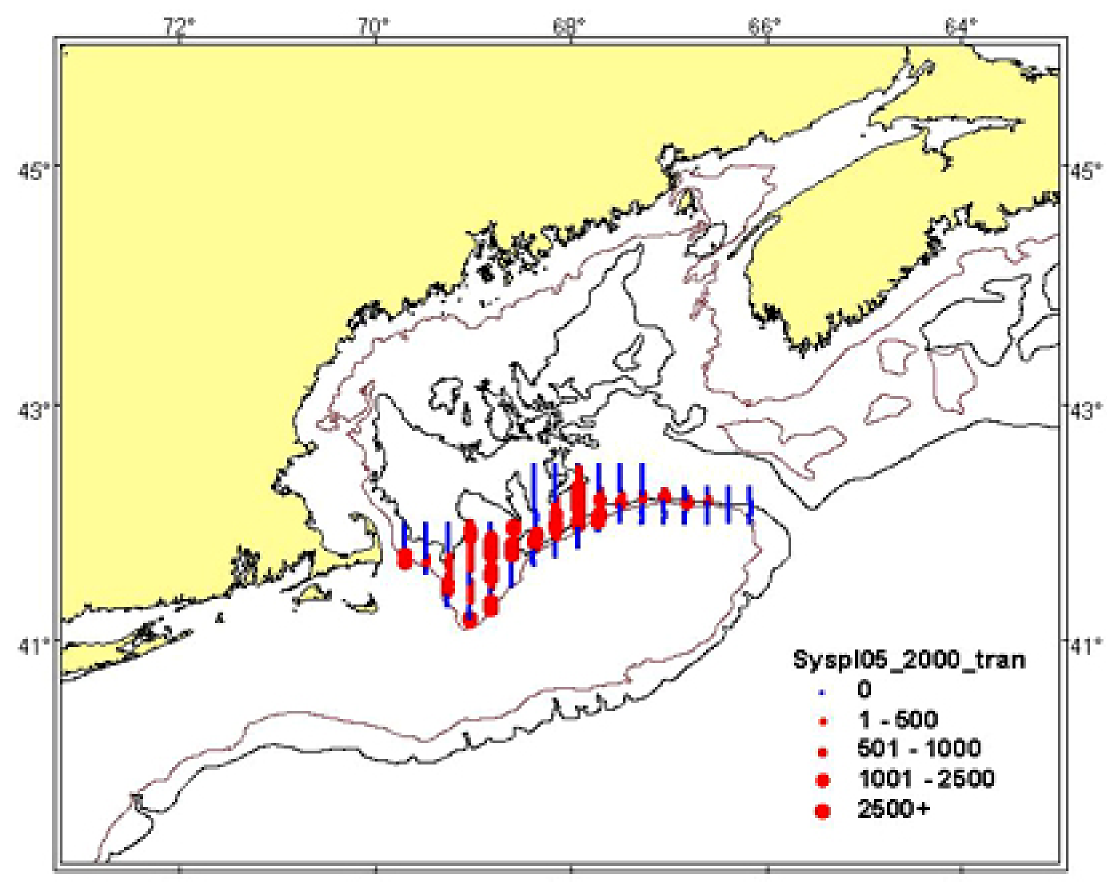

Figure 7.22. Herring backscatter (Sa) on transects from a Parallel survey design on Georges Bank during 2000

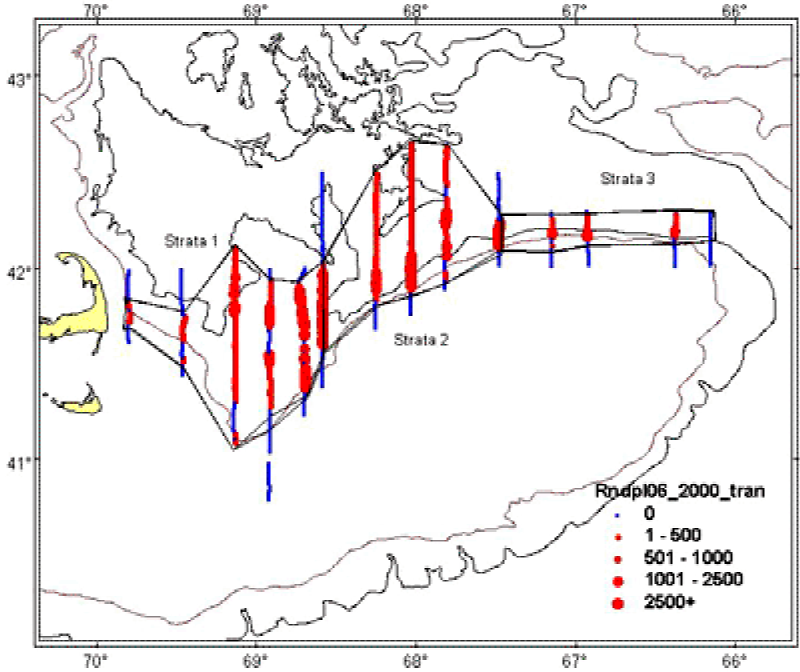

Figure 7.23. Herring backscatter (Sa) on transects from a stratified random survey on Georges Bank during 2000.

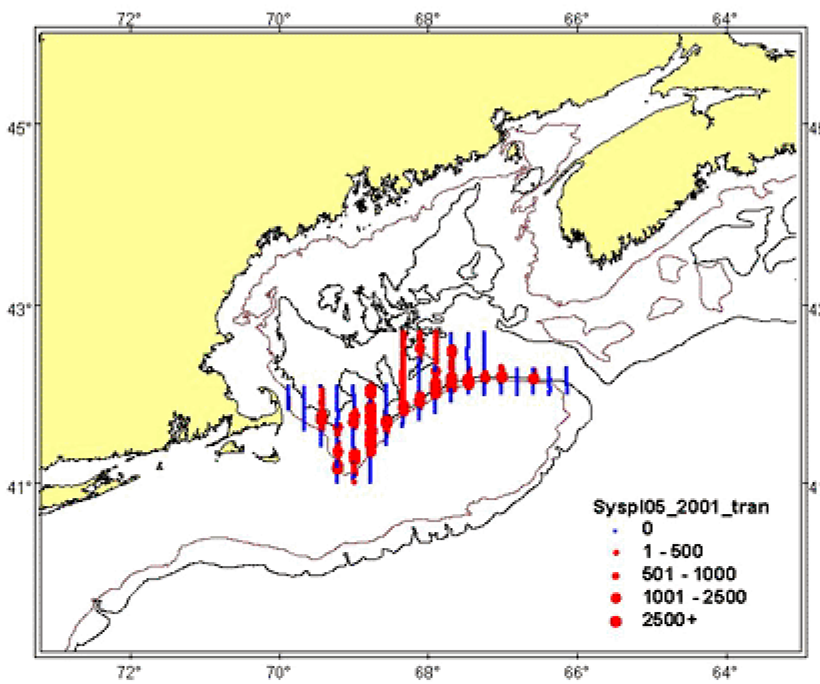

Figure 7.24. Atlantic herring backscatter (Sa) on transects from a parallel survey design on Georges Bank during 2001.

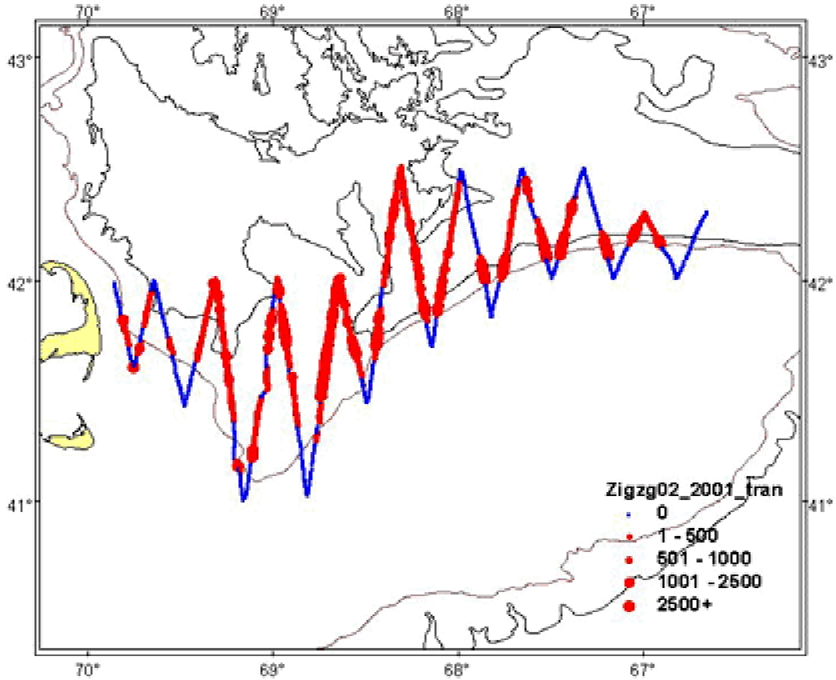

Figure 7.25. Atlantic herring backscatter (Sa) on transects from a zigzag survey design on Georges Bank during 2001.

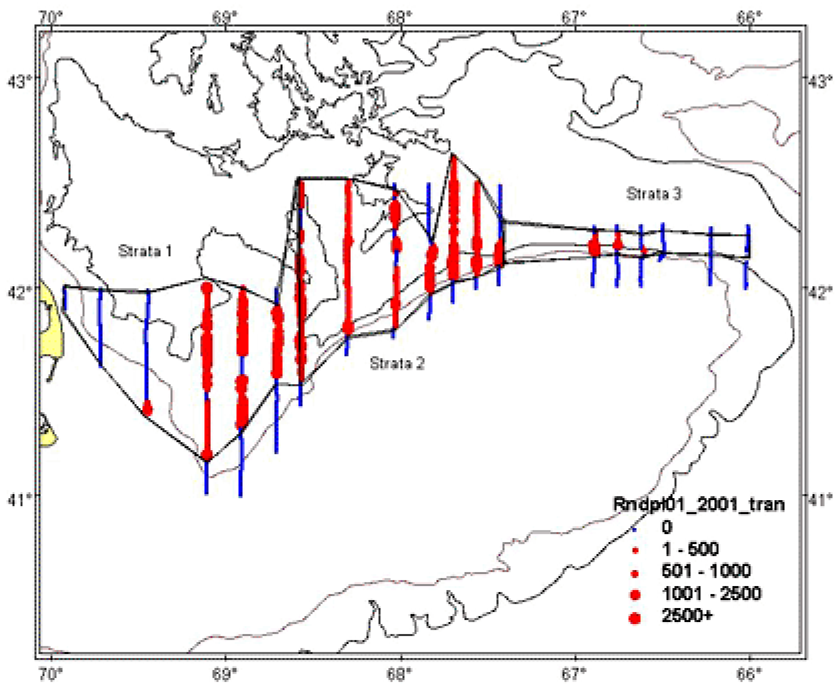

Figure 7.26. Atlantic herring backscatter (Sa) on transects from a stratified random design on Georges Bank during 2001

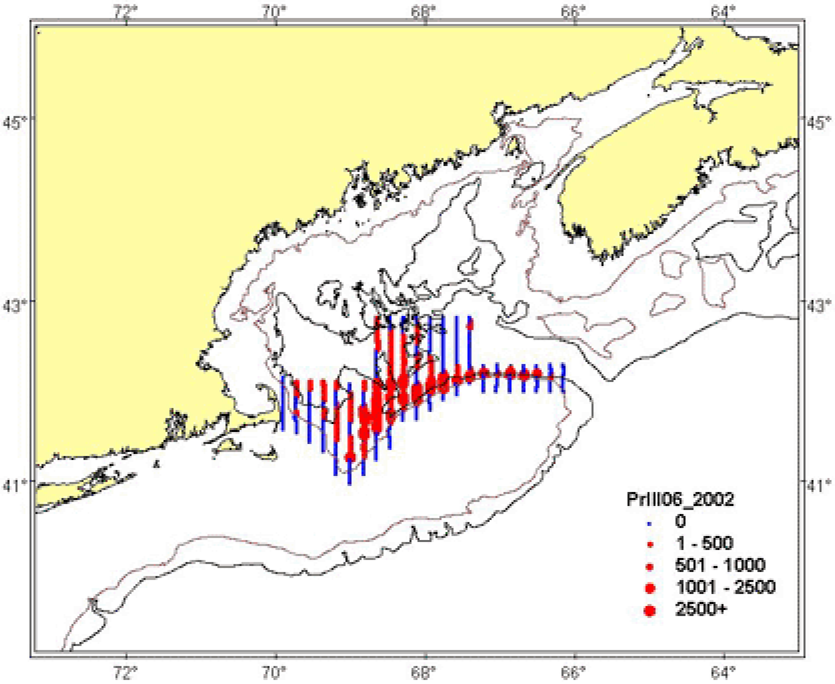

Figure 7.27. Atlantic herring backscatter (Sa) on transects from a parallel survey design on Georges Bank during 2002.

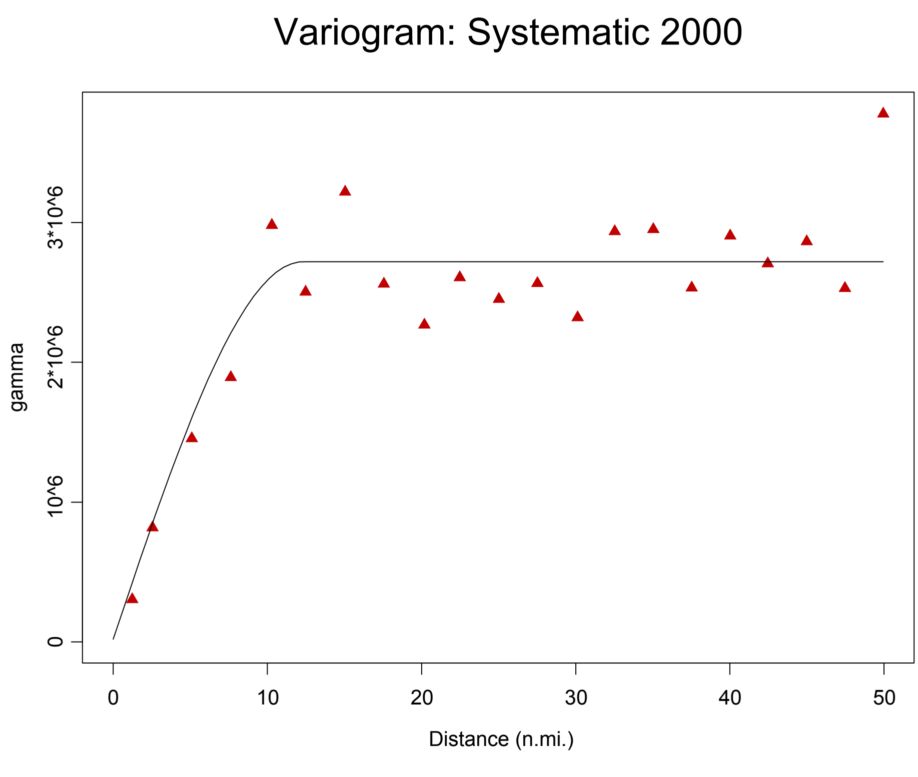

Figure 7.28. Variogram from the parallel survey design on Georges Bank during 2000.

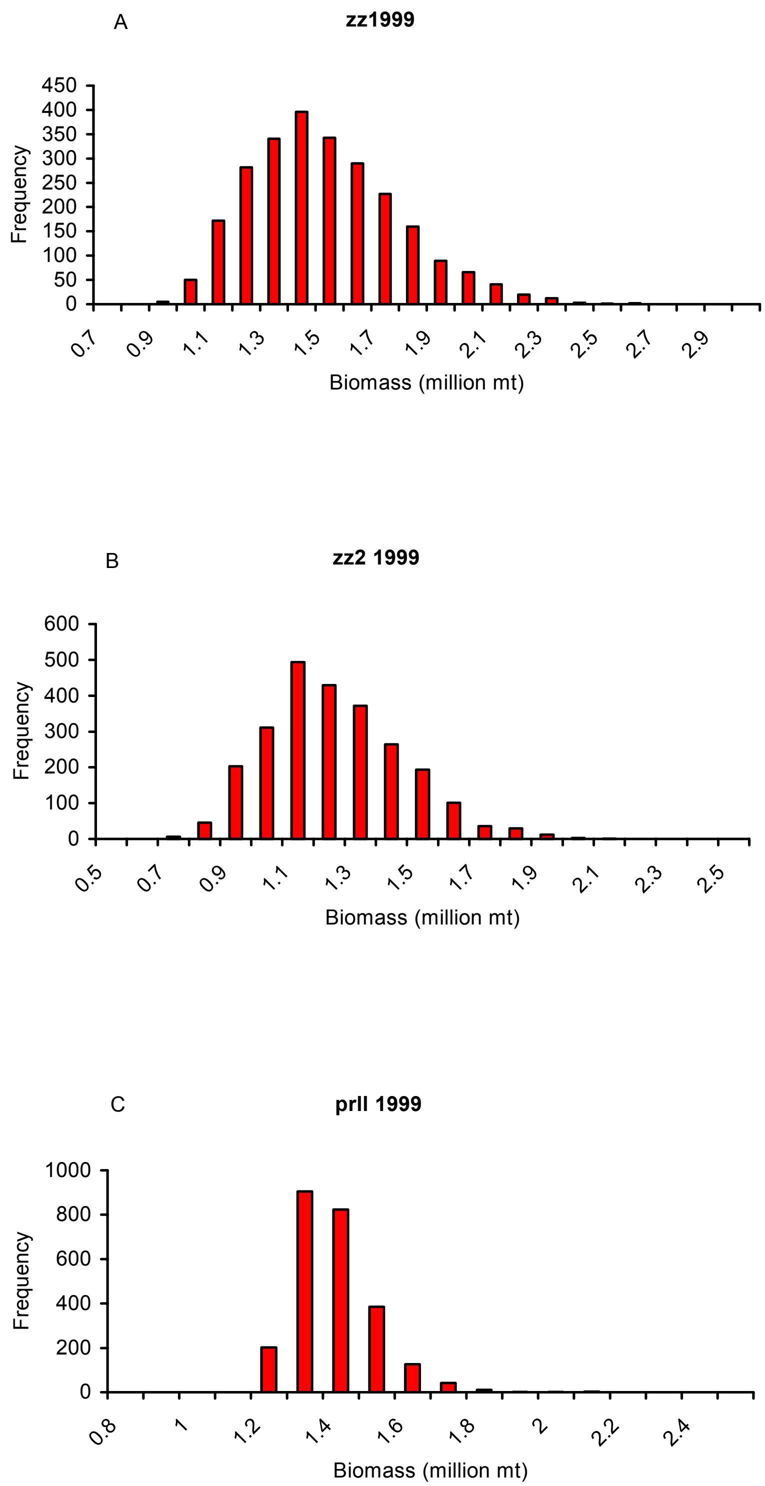

Figure 7.29. Biomass from bootstrap analysis for zigzag part 1 (A), zigzag part 2 (B), and parallel survey (C)designs on Georges Bank during 1999

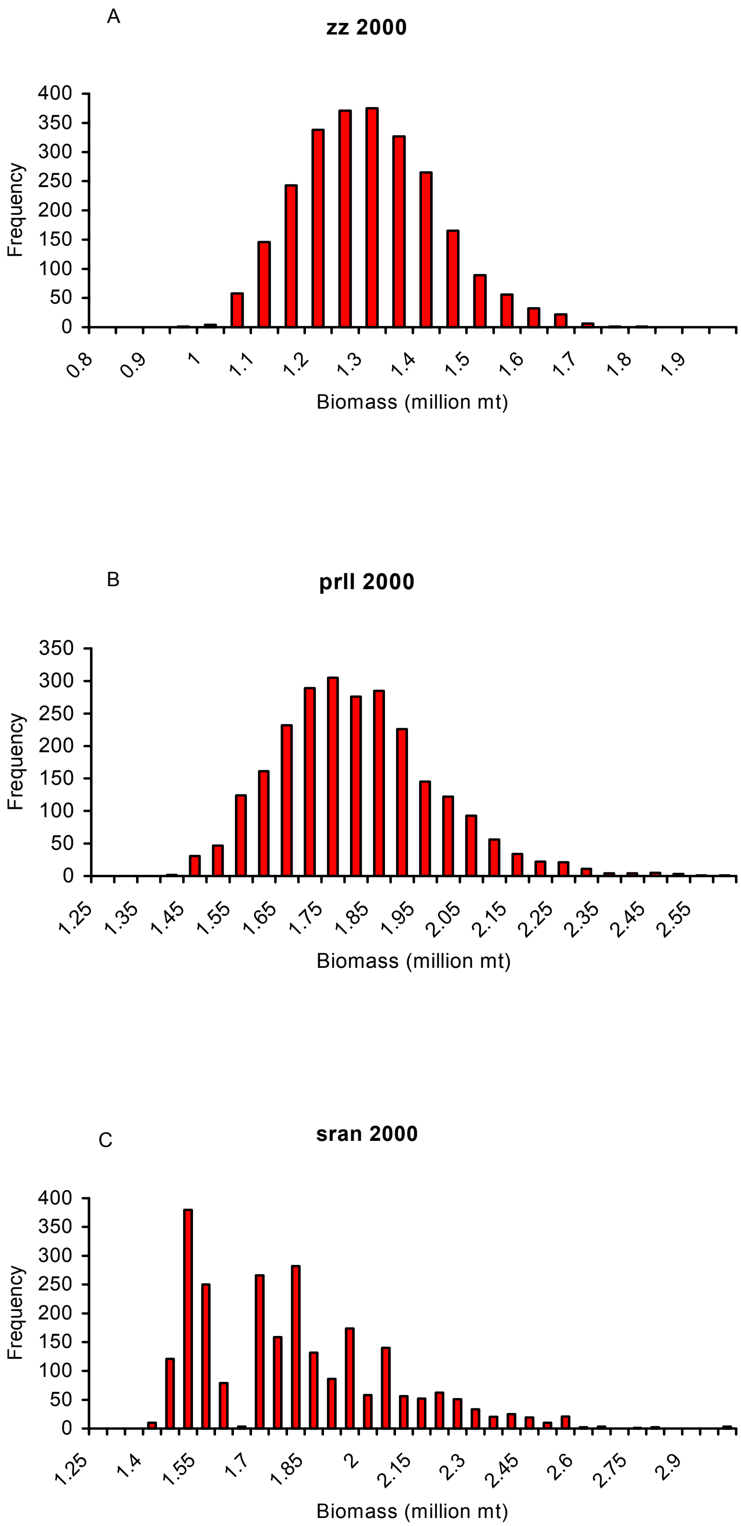

Figure 7.30. Biomass from bootstrap analysis for zigzag (A), parallel (B), and stratified random (C) survey designs on Georges Bank during 2000.

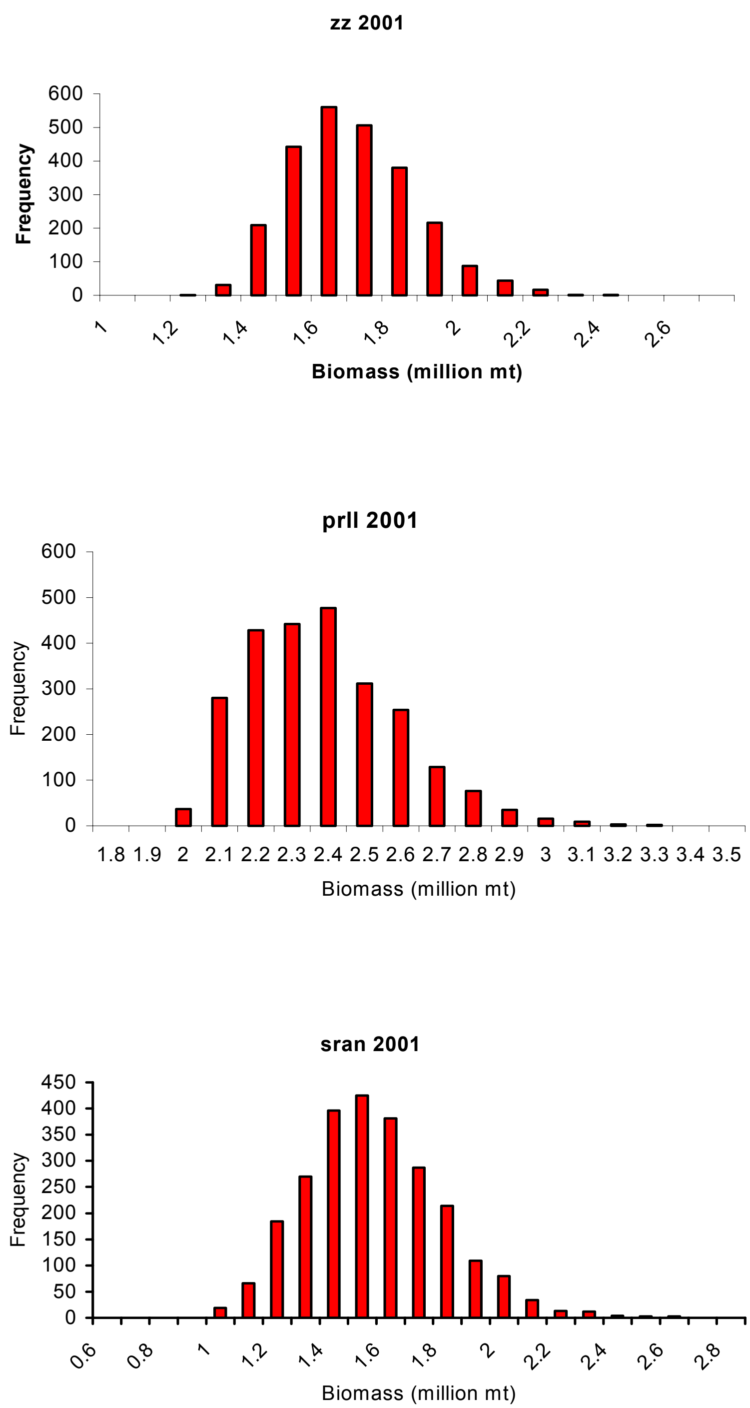

Figure 7.31. Biomass from bootstrap analysis for zigzag (A), parallel (B), and stratified random (C) survey designs on Georges Bank during 2001

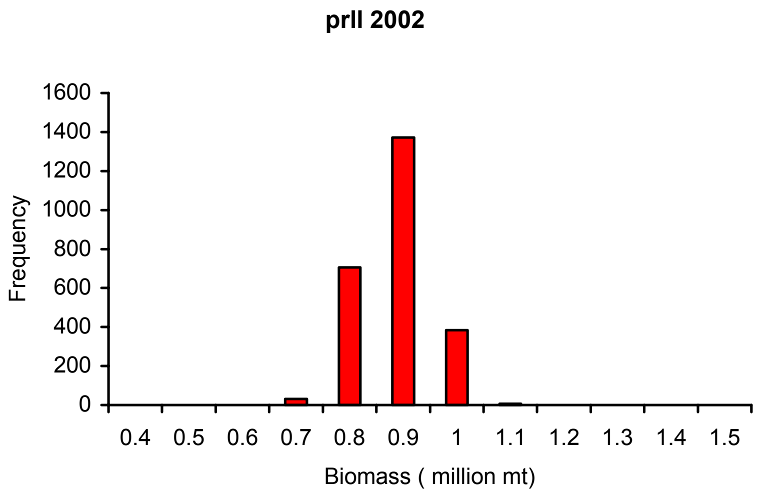

Figure 7.32. Biomass from bootstrap analysis for a parallel survey design on Georges Bank during 2002.

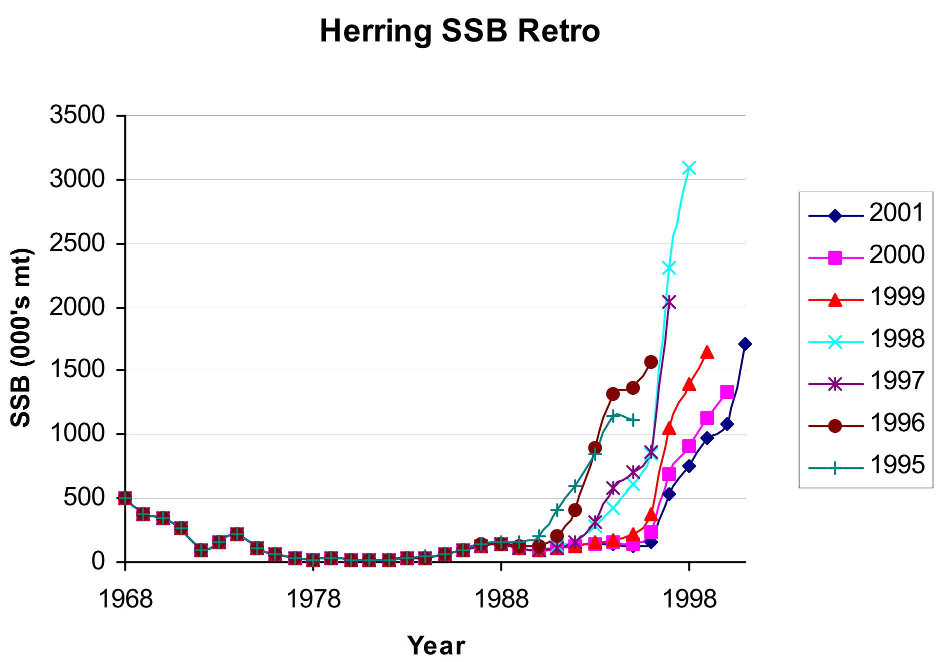

Figure 9.1. Retrospective pattern in spawning stock biomass during 1995-2001 in VPA.